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PATENT & TRADEMARK OFFICE

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Appln. of:	KOEBE, et al
Appln. No.:	10/769,215
Filed:	January 30, 2004
For:	TIRE PRESSURE LOSS DETECTION
Attorney Docket No:	10543-074

Examiner: Unknown
Art Unit: Unknown

Commissioner for Patents
U.S. Patent and Trademark Office
P. O. Box 1450
Alexandria, VA 22313-1450

TRANSMITTAL

Sir:

Attached is/are:

☒ Petition For Granting Of A Corrected Filing Date and Issuance of a Filing Receipt
☒ Attachments A-E
☐
☒ Return Receipt Postcard

Fee calculation and payment:

☐ No additional fee is required.
☐ An extension fee in an amount of $_____ for a _____-month extension of time under 37 C.F.R. § 1.136(a).
☐ A petition or processing fee in an amount of $_____ under 37 C.F.R. § 1.17(_____).
☐ An additional filing fee has been calculated as shown below:

					Small Entity			Other Than Small Entity	
	Claims Remaining After Amendment		Highest No. Previously Paid For	Present Extra	Rate	Add'l Fee	or	Rate	Add'l Fee
Total		Minus			x $9=			x $18=	
Indep.		Minus			x 43=			x $86=	
First Presentation of Multiple Dep. Claim					+$145=			+ $290=	
					$	Total		$	

Fee calculation and payment:

☐ A check in the amount of $_____ to cover the above-identified fee(s) is enclosed.
☐ Please charge Deposit Account No. 06-1500 (VISTEON GLOBAL TECHNOLOGIES, INC.) in the amount of $_____. A copy of this Transmittal is enclosed for this purpose.
☒ The Commissioner is hereby authorized to charge payment of any additional filing fees required under 37 CFR § 1.16 and any patent application processing fees under 37 CFR § 1.17 associated with this paper (including any extension fee required to ensure that this paper is timely filed), or to credit any overpayment, to Deposit Account No. 06-1500. A copy of this Transmittal is enclosed for this purpose.

Respectfully submitted,

June 8, 2004
Date

John M. Card (Reg. No. 48,423)

CERTIFICATE OF MAILING UNDER 37 C.F.R. §1.8

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail, with sufficient postage, in an envelope addressed to: Commissioner for Patents, U.S. Patent and Trademark Office, P. O. Box 1450, Alexandria, VA 22313-1450, on the below date:

Date: June 8, 2004 Name: Terry Wand Signature: Terry Wand

BRINKS HOFER GILSON & LIONE
P.O. Box 10395
Chicago, IL 60610

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Appln. of:	KOEBE, et al		
Appln. No.:	10/769,215	Examiner:	Unknown
Filed:	January 30, 2004	Art Unit:	Unknown
For:	TIRE PRESSURE LOSS DETECTION		
Attorney Docket No:	10543-074		

Commissioner for Patents
U.S. Patent and Trademark Office
P. O. Box 1450
Alexandria, VA 22313-1450

PETITION FOR GRANTING OF A CORRECTED FILING DATE AND ISSUANCE OF A FILING RECEIPT

Sir:

This Petition is filed in accordance with 37 C.F.R. 1.10(d) to accord the above-referenced application a filing date of January 30, 2004, the date of deposit with the United States Postal Service as "Express Mail", and to request issuance of an official Filing Receipt reflecting the same.

Factual Background

On January 30, 2004, the above-referenced patent application (a copy of which is enclosed as Attachment A) was finalized for filing with the United States Patent and Trademark Office (the "Office") and mailed via the U.S. Postal Service's "Express Mail" service. Express Mail label number, EV329459312US, was applied to the transmittal accompanying the application and the application, transmittal and return postcard were placed in the corresponding Express Mail envelope.

This Express Mail envelope, along with several other Express Mail envelopes, were picked up at the law offices of the undersigned on January 30, 2004 by an employee of the United States Postal Service. Written confirmation of this pickup is evidenced by the attached United States Postal Service Pickup Service Statement (enclosed as Attachment B), which clearly bears the signature of the United States Postal Service employee and the pickup date of January 30, 2004. Postal

employees picking up Express Mail at our offices are not permitted by the USPS to fill out the Express Mail Receipt, but are permitted to sign a pickup log.

Upon receipt of the filled in Express Mail Receipt it was noted that the date had been filled in incorrectly as January 31, 2004. A copy of the filled in customer copy of the Express Mail Label, showing the incorrect date in as January 31, 2004, is provided as Attachment C. It is this date that is entered as the filing date on the Official Filing Receipt.

Further evidence of the incorrectness of the date on the Express Mail Receipt is shown by the date provided by the USPTO on the return receipt post card as Attachment D. The post card indicates that the application was physically received by the Office on January 31, 2004, the same day as the filled in date on the Express Mail Receipt.

Requirements For Grantable Petition

According to 37 C.F.R. 1.10(d):

(1) The Petition must be filed promptly;

(2) The number of the Express Mail mailing label must have been placed on the correspondence prior to the original filing;

(3) The Petition must include a showing which establishes that the requested filing date was the date the correspondence was deposited with the USPS as Express Mail prior to the last scheduled pickup for that day.

Conclusion

In accordance with §1.10(d)(1), this Petition is being promptly filed upon discovery of the incorrect filing date marked on the official filing receipt from the Office.

In accordance with §1.10(d)(2), the number of the Express Mailing label EV 329459312US was placed on the original correspondence, as shown on Attachment A.

In accordance with §1.10(d)(3), Attachment A is a copy of the original correspondence (the above-referenced patent application, a Transmittal, 6 sheets of drawings, an Unexecuted Combined Declaration and Power of Attorney, an Information Disclosure Statement, a PTO Form 1449), showing the number of the

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P.O. Box 10395
Chicago, IL 60610

Express Mailing label on the Transmittal. Also enclosed is a copy of the Express Mailing label bearing the incorrect "in-date" of January 31, 2004; a copy of the USPS Pickup Service Statement bearing the number of the "Express Mail" mailing label, the correct date of pickup of January 30, 2004 and the signature of a USPS employee. Also, attached is the return receipt postcard, filed with the application, indicating that the application was physically received by the Office on January 31, 2004. In addition, original signed statements from the person preparing and depositing the application with the USPS is provided as Attachment E. The statement recites all copies of the original correspondence, the mailing label, and pickup service statement, are true copies of the originals.

Accordingly, it is respectfully requested the United States Patent and Trademark Office accord this application a filing date as of January 30, 2004, the date of deposit with the U.S. Postal Service as "Express Mail" an issue an official filing receipt reflecting the same.

Respectfully submitted,

June 8, 2004
Date

John M. Card (Reg. No. 48,423)
Attorney/Agent for Applicant

Enclosures:

Attachment A: Utility Transmittal in duplicate,
6 sheets of drawings,
an Unexecuted Combined Declaration and Power of Attorney,
an Information Disclosure Statement, a PTO Form 1449
Attachment B: United States Postal Service Pickup Service Statement
Attachment C: Customer Copy of the Express Mail Label
Attachment D: Return Receipt Postcard dated 01/31/04
Attachment E: Declaration of Terry Wand

SERIAL NO. ________________ CASE NO. ________________

FILED: ____________________ CLIENT CASE NO. __________

APPLI

THE P AMP

HERE EMS:

- ☐ ____
- ☐ Draw
- ☐ Decla te
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- ☐ Certif
- ☐ Amen
- ☐ Depo
- ☐ Fees mittal
- ☐ Other ____________________

Serial No.: Unknown
Applicant: KOEBE, ET AL.
Client/Matter No.: 10543-074

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Please acknowledge receipt of the below identified:

Items Mailed: Patent Application Transmittal; 20 Pages of Application; 6 Sheets of Drawings; Unexecuted Combined Declaration and Power of Attorney (3 pages); Information Disclosure Statement; One Sheet of Form PTO-1449 and copies of references cited; and a check in the amount of $770.00 for the filing fee.

BRINKS HOFER GILSON & LIONE
By: John M. Card, Reg. No. 48,423
Date of Mailing: **January 30, 2004**

Mailed ____________ Atty JCA ________ Secretary TLW ________

3133

BRINKS, HOFER, GILSON & LIONE
MICHIGAN OPERATING
524 SOUTH MAIN ST., SUITE 200
ANN ARBOR, MI 48104-2921

9-32/720 171

DATE 1/30/04

PAY TO THE ORDER OF UNITED STATES PATENT AND TRADEMARK OFFICE $ 770.00

----SEVEN HUNDRED SEVENTY AND NO/100------------------ DOLLARS

BANK ONE.

Bank One, NA
Detroit, Michigan 48226
www.BankOne.com

FOR 10543-074 filing fee

⑈003133⑈ ⑆072000326⑆ 2050005459OO⑈

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Appln. of:	Andreas Koebe, et al.		
Appln. No.:	Unknown	Examiner:	Unknown
Filed:	Concurrently Herewith	Art Unit:	Unknown
For:	Tire Pressure Loss Detection		
Attorney Docket No:	10543-074		

INFORMATION DISCLOSURE STATEMENT

Sir:

In accordance with the duty of disclosure under 37 C.F.R. §1.56, and more particularly in accordance with 37 C.F.R. §1.97(b), Applicant cites the following references (each listed for the Examiner's convenience on the enclosed Form PTO-1449):

No.	Date of Publication	Patentee/Applicant/Assignee
5,712,616	01/27/1998	Schmitt et al.
6,374,163	04/16/2002	Lou et al.
6,385,553	05/07/2002	Naito et al.
6,450,020	09/17/2002	Naito et al.
6,510,375	01/21/2003	Faye
EP 0 695 653	10/15/1997	Nishikawa, et al.
EP 0 578 826	07/08/1998	Naito et al.
WO 01/87647	11/22/2001	Gustafsson

A copy of each listed reference for which a copy is required under 37 C.F.R. §1.98(a)(2) is also enclosed. As each of the listed references is in English, no further commentary is believed to be necessary, 37 C.F.R. §1.98(a)(3).Applicant respectfully solicits the Examiner's consideration of the listed references and entry thereof into the record of this application.

By submitting this Statement, Applicant is attempting to fully comply with the duty of candor and good faith mandated by 37 C.F.R. §1.56. As such, this Statement is not intended to constitute an admission that any of the enclosed references, or other information referred to therein, constitutes "prior art" or is otherwise "material to patentability," as that phrase is defined in 37 C.F.R. §1.56(a).

Applicant has calculated no fee to be due in connection with the filing of this Statement. However, the Commissioner is authorized to charge any fee deficiency associated with the filing of this Statement to a deposit account, as authorized in the Transmittal accompanying this Statement.

Respectfully submitted,

January 30, 2004
Date

John M. Card (Reg. No. 48,423)
Attorney/Agent for Applicant

Enclosures: Form PTO-1449 (one sheet)
Copies of listed references

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BRINKS HOFER GILSON & LIONE
P.O. Box 10395
Chicago, IL 60610

FORM PTO-1449	APPLICATION NO. Unknown	CASE NO. 10543-074
LIST OF PATENTS AND PUBLICATIONS FOR APPLICANT'S INFORMATION DISCLOSURE STATEMENT	FILING DATE Concurrently Herewith	ART UNIT Unknown
	APPLICANT(S): Andreas Koebe, et al.	

REFERENCE DESIGNATION

U.S. PATENT DOCUMENTS

EXAMINER INITIAL		DOCUMENT NUMBER	DATE	NAME	CLASS/ SUBCLASS	FILING DATE
		5,712,616	01/27/1998	Schmitt et al.		
		6,374,163	04/16/2002	Lou et al.		
		6,385,553	05/07/2002	Naito et al.		
		6,450,020	09/17/2002	Naito et al.		
		6,510,375	01/21/2003	Faye		

FOREIGN PATENT DOCUMENTS

EXAMINER INITIAL		DOCUMENT NUMBER	DATE	COUNTRY	CLASS/ SUBCLASS	TRANSLATION YES	NO
		EP 0 695 653	10/15/1997	EP		X	
		EP 0 578 826	07/08/1998	EP		X	
		WO 01/87647	11/22/2001	Published App.		X	

EXAMINER INITIAL		OTHER ART (Including Author, Title, Date, Pertinent Pages, etc.)

EXAMINER	DATE CONSIDERED

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

In re Application of: Andreas Koebe, et al.
For: Tire Pressure Loss Detection
Attorney Docket No: 10543-074
Express Mail" mailing label number: EV329459312US
Date of Deposit: January 30, 2004

EV329459312US

BRINKS
HOFER
GILSON
& LIONE

UTILITY PATENT APPLICATION TRANSMITTAL

MS Patent Application
Commissioner for Patents
U.S. Patent and Trademark Office
P. O. Box 1450
Alexandria, VA 22313-1450

Sir:

Transmitted herewith is a new application under 37 C.F.R. §1.53(b), including the following elements and other papers:

1. ☒ Specification, including 20 pages of application (including title page, claims and Abstract), 6 sheet(s) of drawings, and the following Appendices:
2. ☒ Combined Declaration and Power of Attorney (3 pages) (☐ Executed ☒ Unexecuted)
3. ☒ Information Disclosure Statement, including Form PTO-1449 (1 sheet) and copies of references cited
4. ☐ Assignment Recordation Cover Sheet and attached assignment to: ______
5. ☐ Other: _____
6. ☒ Return Postcard
7. Fee calculation and payment:

Claims as Filed	Col. 1	Col. 2	Small Entity		or	Other Than Small Entity	
For	No. Filed	No. Extra	Rate	Fee	or	Rate	Fee
Basic Fee				$ 385	or		$ 770
Total Claims	14-20		x$9=	$	or	x$18=	$
Indep. Claims	1-3		x$43=	$	or	x$86=	$
Multiple Dependent Claims Present			+$145=	$	or	+$290=	$
			Total	$	or	Total	$770

*If the difference in col. 1 is less than zero, enter "0" in col. 2.

☒ A check in the amount of $770.00 to cover the filing fee is enclosed.

☐ Please charge my Deposit Account No. 23-1925 in the amount of $_____. A copy of this Transmittal is enclosed.

☒ The Commissioner is hereby authorized to charge payment of the following fees associated with this communication or credit any overpayment to Deposit Account No. 23-1925. A copy of this Transmittal is enclosed.

- ☒ Any additional filing fees required under 37 CFR § 1.16.
- ☒ Any patent application processing fees under 37 CFR §1.17.

☒ The Commissioner is hereby authorized to charge payment of the following fees during the pendency of this application or credit any overpayment to Deposit Account No. 23-1925. A copy of this Transmittal is enclosed.

- ☒ Any filing fees under 37 CFR § 1.16 for presentation of extra claims.
- ☒ Any patent application processing fees under 37 CFR § 1.17.

8. Correspondence Address: Please address all future communications to:

John M. Card
BRINKS HOFER GILSON & LIONE
P.O. Box 10395
Chicago, IL 60610
(734) 302-6000

Respectfully submitted,

Jan 30, 2004
Date

John M. Card (Reg.No. 48,423)
☒ Attorney/Agent Of Record
☐ 37 C.F.R. 1.34(a)

"Express Mail" mailing label number: EV329459312US

Date of Deposit: January 30, 2004

Attorney Docket No. 10543-074

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
APPLICATION FOR UNITED STATES LETTERS PATENT

INVENTORS:	Andreas Koebe, Yongle Lou, Peter Olejnik, and Ines Runge
TITLE:	TIRE PRESSURE LOSS DETECTION
ATTORNEYS:	John M. Card Steven L. Oberholtzer BRINKS HOFER GILSON & LIONE P.O. BOX 10395 CHICAGO, ILLINOIS 60610 (734) 302-6000

TIRE PRESSURE LOSS DETECTION

BACKGROUND

[0001] The present invention relates to air pressure loss detection in one or more tires of a vehicle.

[0002] During the operation of a vehicle, significant loss of pressure in one or more tires may cause the driver to lose control of the vehicle or a tire failure. Moreover, event slight pressure losses in a tire can result in reduced service life for that tire. Therefore, it is desirable to be able to inform the driver that one or more tires are losing pressure, especially before hazardous conditions are reached.

[0003] Certain systems measure the pressure of each tire directly and relay this information to the driver. Other systems measure changes in the effective rolling diameter of the tires caused by losses in pressure or its response to road induced vibration. Yet in other systems the rotational velocities of the tires are measured under certain operating situations to identify conditions of the tires. For instance, loss of air in a tire may cause an increase in rotational resistance of the tire, and hence a perceptible change in the tire rotational velocity.

BRIEF SUMMARY OF THE INVENTION

[0004] As a vehicle maneuvers over a road surface, ground excitation generates angular speed variations or torsional vibration of one or more wheels of the vehicle caused by for-aft displacements of the wheels. The frequency of the speed variations depends on the tire sidewall stiffness, which is mainly influenced by the tire pressure. The angular speed variation of a wheel shifts from a higher frequency to a lower frequency at a given speed when there is tire pressure loss.

[0005] In accordance with the invention, the loss of pressure in one or more tires is monitored by detecting the angular speed variations of one or more wheels of the vehicle and analyzing the frequency of the speed variations over a specified wheel revolution period. Changes in the frequency are related to pressure loss in one or more tires, which is indicated to the driver, for example, by displaying the tire pressure loss information on a display.

[0006] Other features and advantages will be apparent from the following drawings, detailed description, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 illustrates an ABS encoder employed to monitor shifts in torsional vibration of an axle in accordance with an embodiment of the invention.

[0008] FIG. 2 depicts the frequency spectrum for for-aft torsional vibrations of an axle.

[0009] FIG. 3 depicts the distortion of a frequency spectrum caused by pole pitch errors.

[0010] FIG. 4 depicts a frequency spectrum for a tire pressure loss of about 1.2 bars after eliminating the pole pitch error for a vehicle driven on a regular road.

[0011] FIG. 5 depicts a frequency spectrum for a tire pressure loss of about 1.2 bars after eliminating the pole pitch error for a vehicle driven on a rough road.

[0012] FIG. 6 depicts frequency spectrum of data for 1.5 bars and 2.7 bars and respective curve fitted results.

[0013] FIG. 7 depicts the frequency spectra of a front left tire for various pressure losses.

[0014] FIG. 8 depicts the frequency spectra of a right left tire for various pressure losses.

[0015] FIG. 9 depicts the frequency spectra of a front right tire for various pressure losses.

[0016] FIG. 10 depicts the frequency spectra of a rear right tire for various pressure losses.

[0017] FIG. 11 depicts a state diagram for torsional vibration detection in accordance with an embodiment of the invention.

[0018] FIG. 12 depicts a flow diagram of a sequence of steps for the torsional vibration detection in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0019] The following terminology is helpful for understanding various aspects of the present invention:

FFT - Fast Fourier Transform

DFFT - Discrete Finite Fourier Transform

Θ - A finite period of angle (as a multiple of 2π *radian*) for estimating the Fourier transform

N - A finite number of sampled points for estimating the DFFT

θ_n - Angle of the n_{th} signal sampled

$\Delta\theta$ - Angle interval between two consecutive samples,

(i.e. $\Delta\theta = \frac{\Theta}{N}$ $(2\pi \ \ radian))$

Δt_n - A period of time during the n_{th} rotation of $\Delta\theta$

$r(\theta)$ - A signal sampled in the angle $\theta = n\Delta\theta$ (i.e. the time period between two encoder flanks of rising edges or down edges; $r(\theta) = r(n\Delta\theta) = \Delta t_n$)

M - Number of frequencies detected in a frequency spectrum

$\Delta\Omega$ - Angular frequency resolution in the angular domain that is equal to the difference between consecutive frequencies $(cycles/2\pi \ \ radian)$

Ω - Angular frequency $(cycles/2\pi \ \ radian)$ defined in the angular spectrum $\Omega = m\Delta\Omega \ \ m = 0,1,2.3,....M-1$

ω - Angular velocity of an axle (2π $radian$ / sec)

Δf - Frequency resolution in the time domain or difference between consecutive frequencies (Hz)

[0020] During the operation of a vehicle, for example, ground excitation generates torsional vibration or angular speed variations of one or more wheels or other powertrain components of the vehicle, such as the axles of the driven wheels. For example, in FIG. 2 illustrates the frequency spectrum of the vibration caused by such excitations as a vehicle moves along a straight line at speeds at or above 40 kph. As shown, the torsional vibration caused by for-aft excitation in the direction of travel of the vehicle is about 40 Hz. The frequency of the torsional vibration depends on the tire sidewall stiffness, which is mainly influenced by the tire pressure. The torsional vibration of a wheel shifts from a higher frequency to a lower frequency at a given speed when there is a pressure loss in a tire.

[0021] In accordance with various embodiments of the invention, a process or algorithm (see, e.g., FIGs. 11 or 12) detects the tire air state based on the extracted natural frequency of the torsional vibration or angular speed variations of the wheel on which the tire is mounted. The process employs DFFT analysis for analyzing the torsional vibration. A DFFT analysis is disclosed in U.S. Patent No. 6,374,163, the contents of which is incorporated herein in its entirety. Accordingly, in the present invention, vibration analysis through ABS wheel speed sensors enables detecting the torsional frequency shifting and hence tire pressure loss.

[0022] Referring now to FIG. 1, there is shown an ABS encoder 10 with N teeth 12, where during the rotation of the ABS encoder Δt_f and Δt_r represent

the time period between two encoder flanks of rising edges 14 and down edges 16, respectfully. As the wheel rotates, appropriate software, implemented, for example, in an electronic control unit (ECU) of the vehicle, collects the number of tics passing one encoder flank (one tooth). Discontinuities in Δt_f or Δt_r signals may be caused by speed changes, production/mounting variations of encoder, and/or rough roads. The ABS encoder (or tone wheel) produces multiple peak outputs per wheel revolution and is typically based on variable reluctance or Hall effect devices. The ABS encoder is provided to accurately measure wheel speeds for use as inputs for variable anti-lock brakes (ABS), dynamic stability program (DSP) control (and other yaw stability and roll-over stability systems), and traction control systems (TCS).

[0023] A function is sampled at every spaced interval angle and the Fourier Transform is applied in the angular domain $s(\Omega)$, which is a function of the inverse angle θ (i.e., $\Omega = 1/\theta$) expressed in cycles per 2π radian (i.e. $cycles/2\pi$), as given by the expression

$$s(\Omega) = \int_{-\pi}^{\pi} r(\theta)\, e^{-j2\pi\Omega\theta}\, d\theta \qquad (1)$$

[0024] The Fourier integral transforms can be rewritten for discrete sample data systems. In the angular domain, Θ is the sampling angle and N is the number of samples taken during a period of Θ. In general, Θ is chosen as a multiple of 2π radian. Accordingly, the spectrum is given by the expression:

$$s(m\Delta\Omega) = \frac{\Theta}{N}\sum_{n=0}^{N-1} r(n\Delta\theta)\, e^{-j2\pi mn/N} \qquad m = 0, 1, 2, \ldots, \frac{N}{2} \qquad (2)$$

where the angle interval $\Delta\theta$ is considered a constant value, namely,

$$\Delta\theta = \frac{2\pi}{Number\ of\ Teeth\ ABS\ encoder} \quad (3)$$

and the rotation angle is

$$\theta = n\,\Delta\,\theta \quad (4)$$

The angular frequency resolution is provided by the expression

$$\Delta\Omega = \frac{2\,\pi}{\Theta}\ cycles/2\pi \quad (5)$$

where the angular frequency Ω is represented as $m\Delta\Omega$.

Accordingly, the Fourier integral transforms a discrete sampled angular domain to the angular frequency domain in units of $cycles/2\pi$.

[0025] The spaced interval in time Δt_n represents a period of time during the n_{th} rotation of $\Delta\theta$, and Δt_n in general is not a constant because of the variations of the angular velocity of a given wheel.

[0026] If the sequence of sampled values is

$$r(n\Delta\theta) = \Delta t_n \quad (6)$$

then from equation (2), the DFFT algorithm uses the following expression which applies equally to series of angles in real space:

$$s(m\Delta\Omega) = \frac{\Theta}{N}\sum_{n=0}^{N-1}\Delta t_n\ e^{-i2\pi mn/N} \qquad m = 0,1,2,\dots\frac{N}{2} \quad (7)$$

Here, a contribution of spaced interval in time Δt_n is $\Delta t_n\ e^{-i2\pi mn/N}$.

[0027] For the analysis of the torsional vibration, the sampling length N is calculated by the equation:

$$N = \frac{\Theta}{\Delta\theta} \tag{8}$$

[0028] A continuous contribution of each encoder flank Δt_n $(n = 0,1,2,3,\ldots,N-1)$ to all the predefined frequencies is $\Delta t_n \times e^{-j2\pi mn/N}$ $M = 0,1,2,\ldots,M-1$. Note that, in general, more than one encoder flank is rotated during a software loop, and all the contributions of these encoder flanks to the spectrum are completed within the same software loop.

[0029] In equation (2) the task of calculating the frequency spectrum is divided into N sub-tasks $\Delta t_n \times e^{-j2\pi mn/N}$ $N = 0,1,2,\ldots,N-1$. Hence, the total contribution for Δt_n $(n = 0,1,2,3,\ldots,N-1)$ creates a single angular frequency spectrum:

$$s(m\Delta\Omega) = \frac{\Theta}{N}\sum_{n=0}^{N-1}\Delta t_n \times e^{-j2\pi mn/N} \qquad m = 1,2,3,\ldots,M-1$$

The total tics $\sum_{n=0}^{N-1}\Delta t_n$ are accumulated to calculate an angular velocity ω.

[0030] Rewriting equation (7) in complex space, the frequency spectrum is given by:

$$s_r(m\Delta\Omega) = \frac{\Theta}{N}\left(\sum_{n=0}^{N-1}\Delta t_n \cos\left(\frac{2\pi mn}{N}\right) - j\sum_{n=0}^{N-1}\Delta t_n \sin\left(\frac{2\pi mn}{N}\right)\right) \tag{9}$$
$$m = 0,1,2,\ldots,\frac{N}{2}$$

and the amplitude of the angular frequency is:

$$|s_r(m\,\Delta\Omega)| = \frac{\Theta}{N}\sqrt{\left(\sum_{n=0}^{N-1}\Delta t_n \cos\left(\frac{2\pi m n}{N}\right)\right)^2 + \left(\sum_{n=0}^{N-1}\Delta t_n \sin\left(\frac{2\pi m n}{N}\right)\right)^2} \qquad (10)$$

$$m = 0, 1, 2, \ldots, \frac{N}{2}$$

[0031] Note that the pitch of the teeth around the encoder tone wheel circumference is not constant because of variations in manufacturing tolerances, and therefore unbalanced variations for every revolution of tire occurs. Frequencies associated with these variations are referred to as pole pitch frequencies, and a pole pitch error is defined as the maximum tolerance on the teeth of the encoder tone wheel.

[0032] As the tire rotates, the pitch error will periodically create additional vibration in the frequency spectrum. These additional frequencies make it more difficult to find a peak torsional vibration in the angular domain. Therefore, in accordance with the invention, the pole pitch frequencies of the single spectrum are eliminated before proceeding with the detection algorithm or process.

[0033] Specifically, in the angular domain, pole pitch vibration occurs where the angular frequency Ω is equal to a multiple of $cycles/2\pi\ radian$. Although there is no relation between pole pitch vibration and the vehicle speed in the angular domain, it is easier to eliminate pole pitch vibration in the angular domain than in the time domain because the vibration occurs at fixed angular frequencies in the angular domain.

[0034] FIG. 3 shows an angular frequency spectrum with and without pole pitch frequencies as a vehicle is driven on a regular road at the speed of about 80.0 kph, illustrating that pole pitch error distorts the frequency spectrum.

[0035] Although the spectrum in FIG. 3 is shown in the angular frequency domain, for vehicle vibration analysis, it is more convenient to express the amplitude of surface profiles in terms of the time frequency in Hz rather than in terms of the angular frequency in $cycles/2\pi\ radian$ since the vehicle vibration is a function of time. Hence, the angular frequency spectrum Ω in $cycles/2\pi$ is transferred to the time frequency spectrum in Hz with the following expression:

$$f\ Hz = \Omega(cycles\ /2\pi\ radian) \times \omega\ \ (2\pi\ radian\ /\sec) \tag{11}$$

where

Ω - Angular frequency ($cycles/2\pi\ radian$)

ω - Angular velocity of a wheel ($2\pi\ radian\ /\sec$) .

And the amplitude of the angular profile in terms of the angular frequency $A_\theta(\Omega)$ is transferred to the temporal frequency $A_t(f)$, according to the expression:

$$A_t(f) = \frac{A_\theta(\Omega)}{\omega} \tag{12}$$

where

A_t = amplitude of the temporal frequency spectrum, and

A_θ = amplitude of the angular frequency spectrum.

[0036] FIG. 4 shows in the time frequency domain that after the pole pitch errors are eliminated, the peak for-aft torsional vibration shifts from 47.0 Hz to 35.0 Hz for a tire pressure loss of 1.2 bars for a vehicle driven over a regular road along a substantially straight line at a speed of about 80.0 kph. FIG. 5 shows the peak for-aft torsional vibration shifts from 42.0 Hz to 35.0 Hz for a tire pressure loss of 1.2 bar for a vehicle driven over a rough road at a speed of about 40 kph.

[0037] As can be seen FIGs. 4 and 5, even after eliminating pole pitch error, a single frequency spectrum still includes noise or deviation. Therefore, to eliminate deviation of the single spectrum, an averaging spectrum $s_p(m\Delta\Omega)$ is introduced by combining the continuous K single spectra according to the expression:

$$s_p(m\Delta\Omega) = \sum_{k=0}^{K-1} s_k(m\Delta\Omega) \qquad m = 1,2,3,\ldots, M-1 \tag{13}$$

[0038] Curve-fitting is then applied to the series of averaged frequency spectra. Specifically, a peak torsional vibration frequency F_0 $(cycles/2\pi)$ in the angular domain is curve fitted according to the expression:

$$F_0 = -\frac{\Delta_b}{2\times\Delta_a} \tag{14}$$

where,

$$\Delta_a = \begin{vmatrix} \sum_{m=M_1}^{M_2-1} x_m^2 y_m & \sum_{m=M_1}^{M_2-1} x_m^3 & \sum_{m=M_1}^{M_2-1} x_m^2 \\ \sum_{m=M_1}^{M_2-1} x_m y_m & \sum_{m=M_1}^{M_2-1} x_m^2 & \sum_{m=M_1}^{M_2-1} x_m \\ \sum_{m=M_1}^{M_2-1} y_m & \sum_{m=M_1}^{M_2-1} x_m & M_2 - M_1 \end{vmatrix} \tag{15a}$$

$$\Delta_b = \begin{vmatrix} \sum_{m=M_1}^{M_2-1} x_m^4 & \sum_{m=M_1}^{M_2-1} x_m^2 y_m & \sum_{m=M_1}^{M_2-1} x_m^2 \\ \sum_{m=M_1}^{M_2-1} x_m^3 & \sum_{m=M_1}^{M_2-1} x_m y_m & \sum_{m=M_1}^{M_2-1} x_m \\ \sum_{m=M_1}^{M_2-1} x_m^2 & \sum_{m=M_1}^{M_2-1} y_m & M_2 - M_1 \end{vmatrix} \tag{15b}$$

and

$$\begin{aligned} x_m &= m\Delta\Omega \\ y_m &= S_p(m\Delta\Omega) \quad m = M_1, M_1+1, \ldots, M_2-1 \end{aligned} \tag{16}$$

[0039] The range of the curve-fitting is determined by the values of M_1 and M_2, which are functions of the angular velocity ω.

[0040] A 'BAD' spectrum is rejected if the fitted curve regresses to a straight line (i.e., $if\ \Delta_a \cong 0$), if the peak position is out of the pre-defined range, or if the calculation overflows.

[0041] As mentioned above, it is more convenient to characterize vehicle vibrations in the time frequency domain rather than in the angular frequency domain. Therefore, after calculating the peak torsional vibration from the frequency spectrum, the process maps the peak torsional vibration from angular domain to the time domain. That is, the process continues to calculate a series of frequency observations and determines an initial torsional frequency (f_0) in the time frequency domain based on the observations. Specifically, the peak torsional vibration is mapped to the frequency domain (Hz) according to:

$$f_0 = F_0 \times \omega_0 \tag{17a}$$

For example, assuming $\Theta = 2\pi \times I$ and the tic time is $\mu = 4 \times 10^{-6}$ sec, then the angular velocity is

$$\omega_n = \frac{1}{\left(\sum_{n=0}^{N-1} \Delta t_n\right) / I \times 4 \times 10^{-6}} \quad (2\pi / \sec) \tag{17b}$$

where I is a predefined number of sampling cycles.

[0042] FIG. 6 illustrates the results of curve-fitting applied to the frequency spectrum generated for a vehicle driven over a rough road at the speed of about 60.0 kph after mapping to the time frequency domain. As shown, the peak

frequency shifts from 40.0 Hz to 35.0 Hz during a tire pressure loss from 2.7 bars to 1.5 bars.

[0043] After calculating the initial frequency, the process makes adjustments to the frequency over time. Even if the vehicle changes speed, the process continues to calculate the single spectrum, the averaging spectrum, and the peak of angular frequency in the angular domain and maps the peak F_i in the angular domain to the time domain f_i ($i = 1,2,3,\ldots$) by the aforementioned process, that is,

$$f_i = F_i \times \omega_i, \quad i = 1,2,3,\ldots,I,\ldots \tag{18}$$

[0044] A filtering calculation is also applied to the series of observed values. Moreover, when i reaches the predefined value I, the process outputs and continues to update the peak frequency of the torsional vibration in real time.

[0045] The aforementioned process is able to detect pressure losses in more than one tire, since, for example, tire pressure loss in the front left tire causes vibration shifting in that tire but does not impact the performance of the front right tire and vice versa. Similarly, vibration of the rear left tire is isolated from the vibration of the rear right tire and vice versa.

[0046] As an example, the process was implemented in a front-wheel drive vehicle driven on a rough road at about 60 kph, in which the tire pressure of the front right tire was 2.3 bars and that of the rear right tire was 2.1 bars. The tire pressure of the front left and rear left tires were changed to 1.5 bars, 1.9 bars, and 2.5 bars. As shown In FIG. 7, pressure loss in the front left tire caused the peak for-aft vibration to shift from 47.3 Hz to 40.9 Hz. As shown in FIG. 8, pressure loss in the rear left tire shifted the peak for-aft vibration from 47.0 Hz to 43.8 Hz.

[0047] Note also in FIGs. 7 and 8 that the amplitude of the peak vibration associated with the rear left tire is less than that of the front left tire. This is expected, since in a front wheel drive vehicle torsional compliance is provided by the front wheel axles and other powertrain components. The non-driven rear wheels, on the other hand, have very little connected components and therefore there is no significant coupled torsional compliance associated with the rear wheels.

[0048] FIG. 9 illustrates that there is no significant shift in the peak for-aft vibration associated with the front right tire. That is, the front left axle vibration does not impact the performance of the front right axle. Similarly, FIG. 10 shows that there is no significant shift for the rear right tire.

[0049] The above described process is illustrated in FIG. 11 as a state diagram 100 and in FIG. 12 as a flow diagram of a process of steps 200. Referring in particular to FIG. 12, after initiating in step 202, the process 200 determines the discrete (Dt) contribution in step 204 from which the real and imaginary components are obtained to calculate the spectrum in step 206.

[0050] In step 208, after creating the single spectrum, the process 200 eliminates the pole pitch error and in step 210 combines the continuous single spectra to an averaging spectrum in the angular domain. In step 212, the process 200 curve fits the averaged spectrum and maps the peak frequency of the curve-fitted spectrum from the angular domain to the time domain in step 214. Subsequently, the process 200 filters the peak frequency and makes long-term adjustments to the peak frequency over time in step 216. As mentioned above, the process 200 continues to calculate the torsional vibration frequency, even when the

vehicle speed changes, and applies statistical analysis to the series of observed data to extract the best value of the estimated frequency. This update is used to detect the shift in the torsional vibration frequency, which is related to the tire pressure loss of one or more tires in step 218. The results are displayed in step 220, and the analysis subsequently ends.

[0051] Other embodiments are within the scope of the following claims.

CLAIMS

What is claimed is:

1. A method of detecting the tire pressure loss in a vehicle, comprising:

detecting angular speed variations of one or more wheels of the vehicle over a specified number of wheel revolutions;

analyzing the frequency of the angular speed variations;

eliminating pole pitch errors in a single angular spectrum;

mapping a peak frequency from angular domain to time domain;

determining if the frequency changes over the time domain;

relating frequency changes to pressure loss in the tire; and

indicating the pressure loss to the driver of the vehicle.

2. The method of claim 1 wherein the determining includes determining if the frequency shifts from a higher frequency to a lower frequency at a given vehicle speed.

3. The method of claim 1 wherein the detecting includes detecting the vibration with an ABS encoder.

4. The method of claim 1 further comprising averaging a series of continuous single frequency spectra.

5. The method of claim 4 further comprising curve fitting the averaged frequency spectrum in the angular domain.

6. The method of claim 5 further comprising calculating the peak frequency from the averaged frequency spectrum.

7. The method of claim 6 further comprising making long-term adjustments by filtering a series of peak frequencies.

8. The method of claim 1 wherein the determining includes detecting shifts in the peak frequency.

9. The method of claim 8 wherein the indicating includes presenting tire pressure loss information on a display viewed by the driver of the vehicle.

10. The method of claim 1 further comprising employing Fast Fourier Transforms for transforming a discrete sampled angular domain to an angular frequency domain.

11. The method of claim 10 further comprising employing Discrete Fast Fourier Transforms.

12. The method of claim 1 wherein the detecting includes detecting the angular speed variations of four wheels.

13. The method of claim 12 wherein the indicating includes indicating pressure loss in one or more tires of four tires mounted on the respective wheels.

14. The method of claim 1 wherein the detecting occurs at vehicle speeds of at least 40 kph.

ABSTRACT

The present invention is directed to monitoring the loss of pressure in one or more tires by detecting the angular speed variations of one or more wheels of the vehicle over a specified wheel revolution period and analyzing the vibration of the speed various. Changes in the frequency are related to pressure loss, which is indicated to the driver, for example, by displaying the tire pressure loss information on a display.

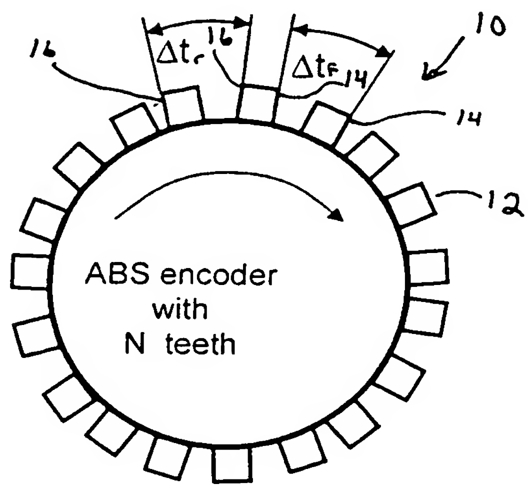
10
12
14
14
16
16
Δt_r
Δt_F
ABS encoder
with
N teeth

FIG. 1

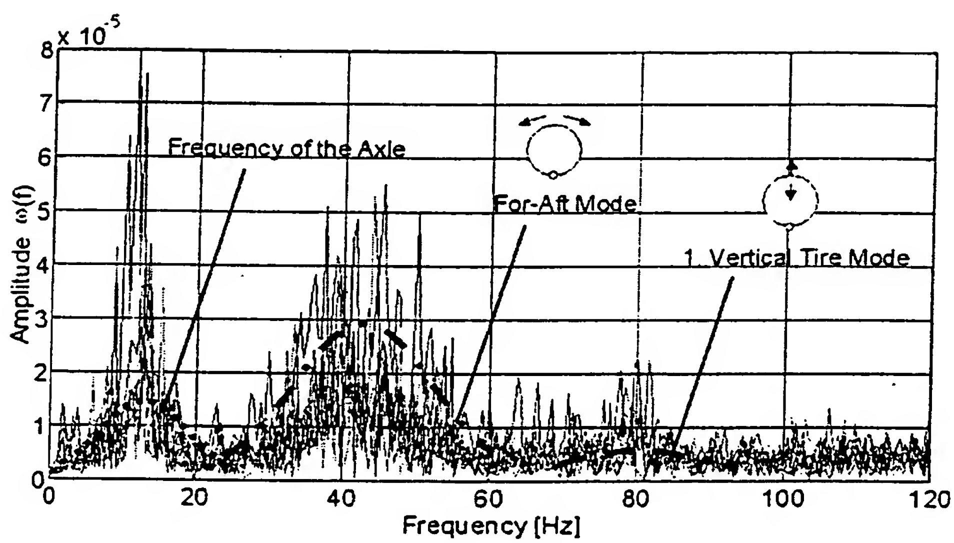
x 10^-5
Frequency of the Axle
For-Aft Mode
1. Vertical Tire Mode
Amplitude ω(f)
Frequency [Hz]
0
20
40
60
80
100
120
0
1
2
3
4
5
6
7
8

FIG. 2

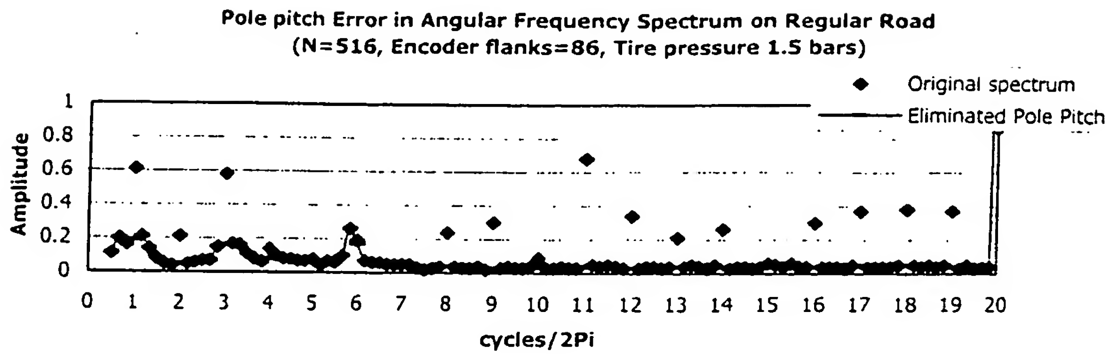

FIG. 3

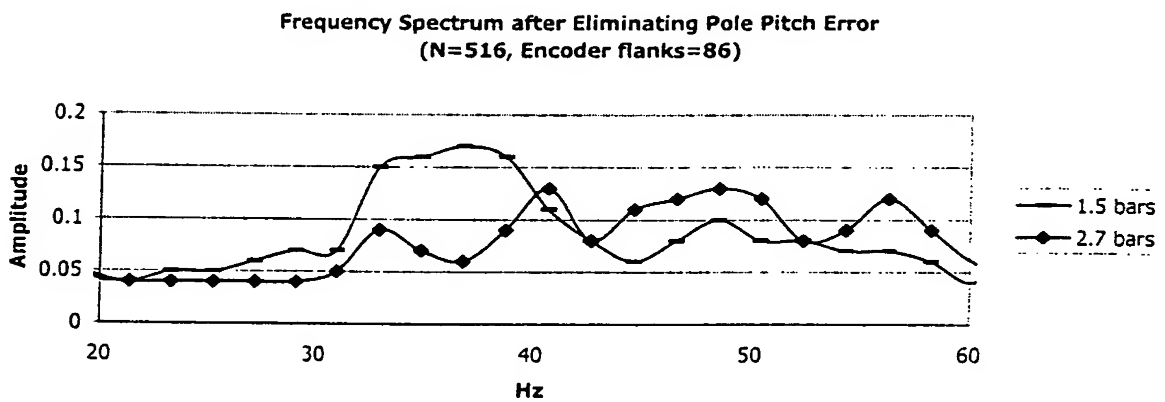

FIG. 4

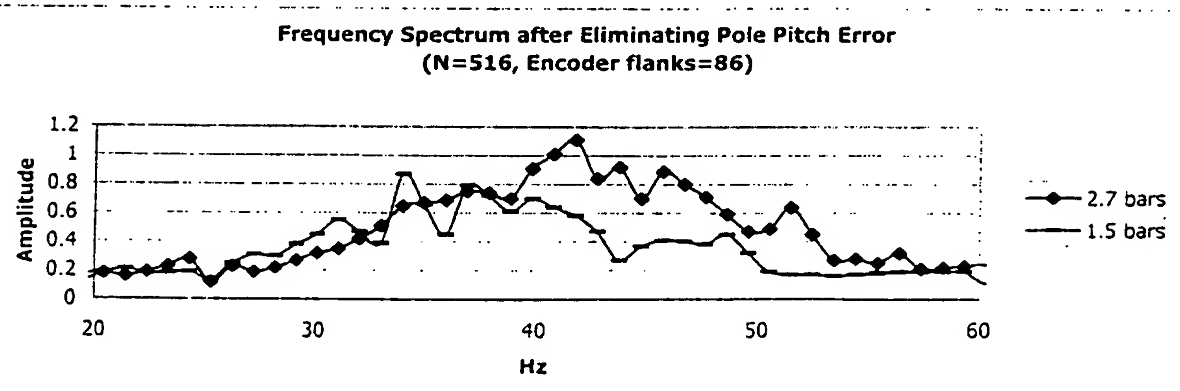

FIG. 5

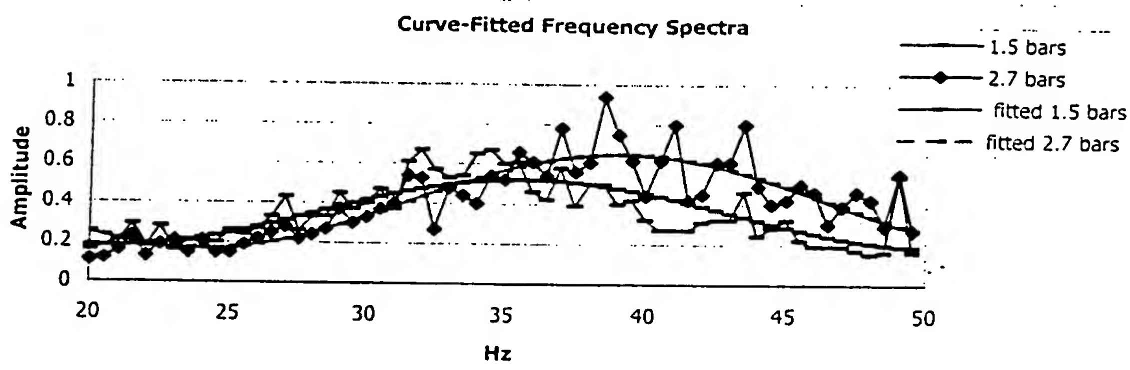

FIG. 6

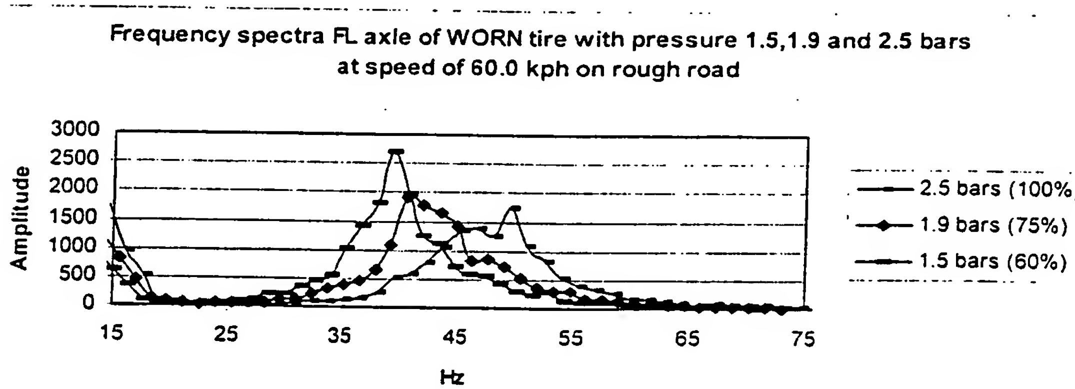

FIG. 7.

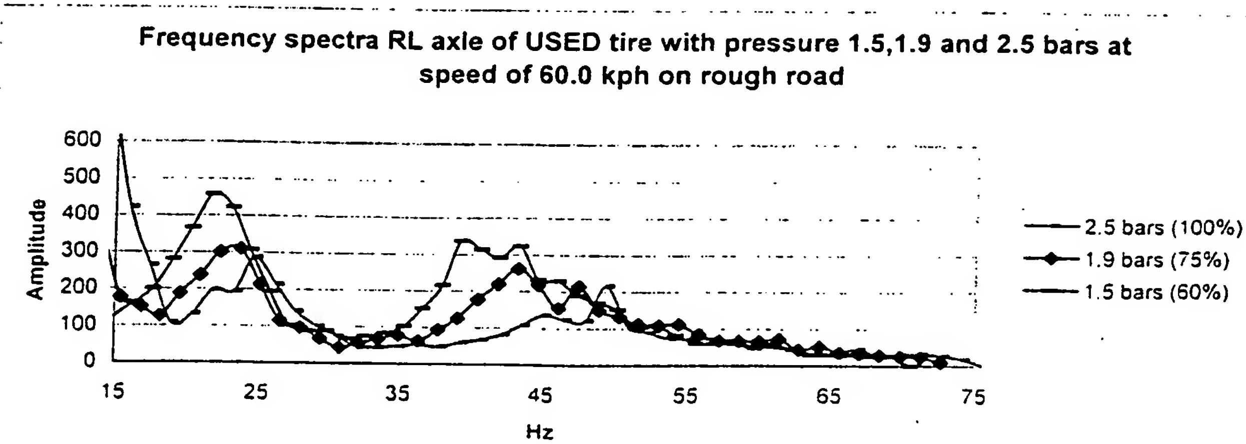

FIG. 8

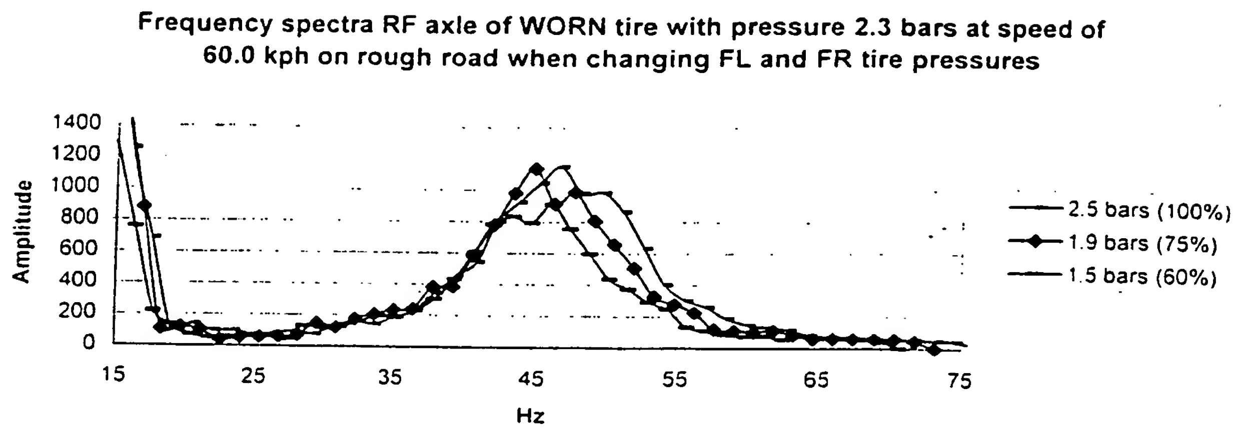
Frequency spectra RF axle of WORN tire with pressure 2.3 bars at speed of 60.0 kph on rough road when changing FL and FR tire pressures
Amplitude
1400
1200
1000
800
600
400
200
0
15
25
35
45
55
65
75
Hz
2.5 bars (100%)
1.9 bars (75%)
1.5 bars (60%)

FIG. 9

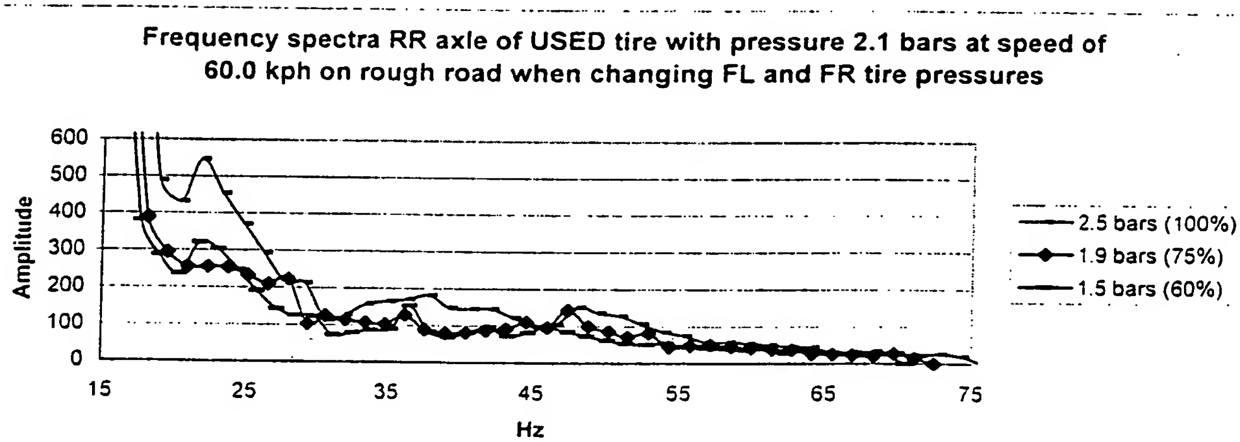
Frequency spectra RR axle of USED tire with pressure 2.1 bars at speed of 60.0 kph on rough road when changing FL and FR tire pressures
Amplitude
600
500
400
300
200
100
0
15
25
35
45
55
65
75
Hz
2.5 bars (100%)
1.9 bars (75%)
1.5 bars (60%)

FIG. 10

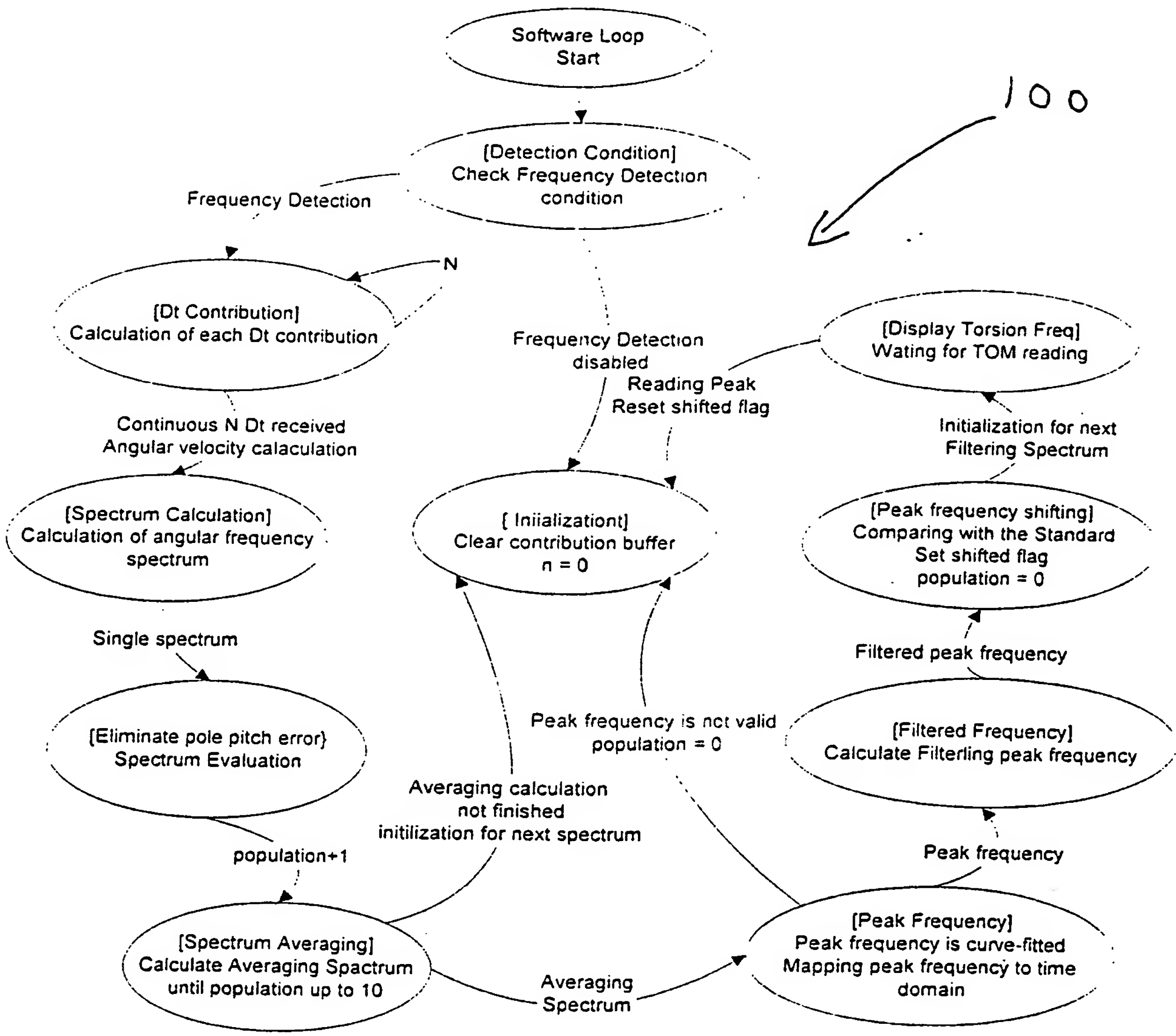
Software Loop
Start
100
[Detection Condition]
Check Frequency Detection
condition
Frequency Detection
N
[Dt Contribution]
Calculation of each Dt contribution
Frequency Detection
disabled
[Display Torsion Freq]
Wating for TOM reading
Reading Peak
Reset shifted flag
Continuous N Dt received
Angular velocity calaculation
Initialization for next
Filtering Spectrum
[Spectrum Calculation]
Calculation of angular frequency
spectrum
[Iniialization]
Clear contribution buffer
n = 0
[Peak frequency shifting]
Comparing with the Standard
Set shifted flag
population = 0
Single spectrum
Filtered peak frequency
[Eliminate pole pitch error]
Spectrum Evaluation
Peak frequency is not valid
population = 0
[Filtered Frequency]
Calculate Filterling peak frequency
Averaging calculation
not finished
initilization for next spectrum
population+1
Peak frequency
[Spectrum Averaging]
Calculate Averaging Spactrum
until population up to 10
Averaging
Spectrum
[Peak Frequency]
Peak frequency is curve-fitted
Mapping peak frequency to time
domain

FIG. 11

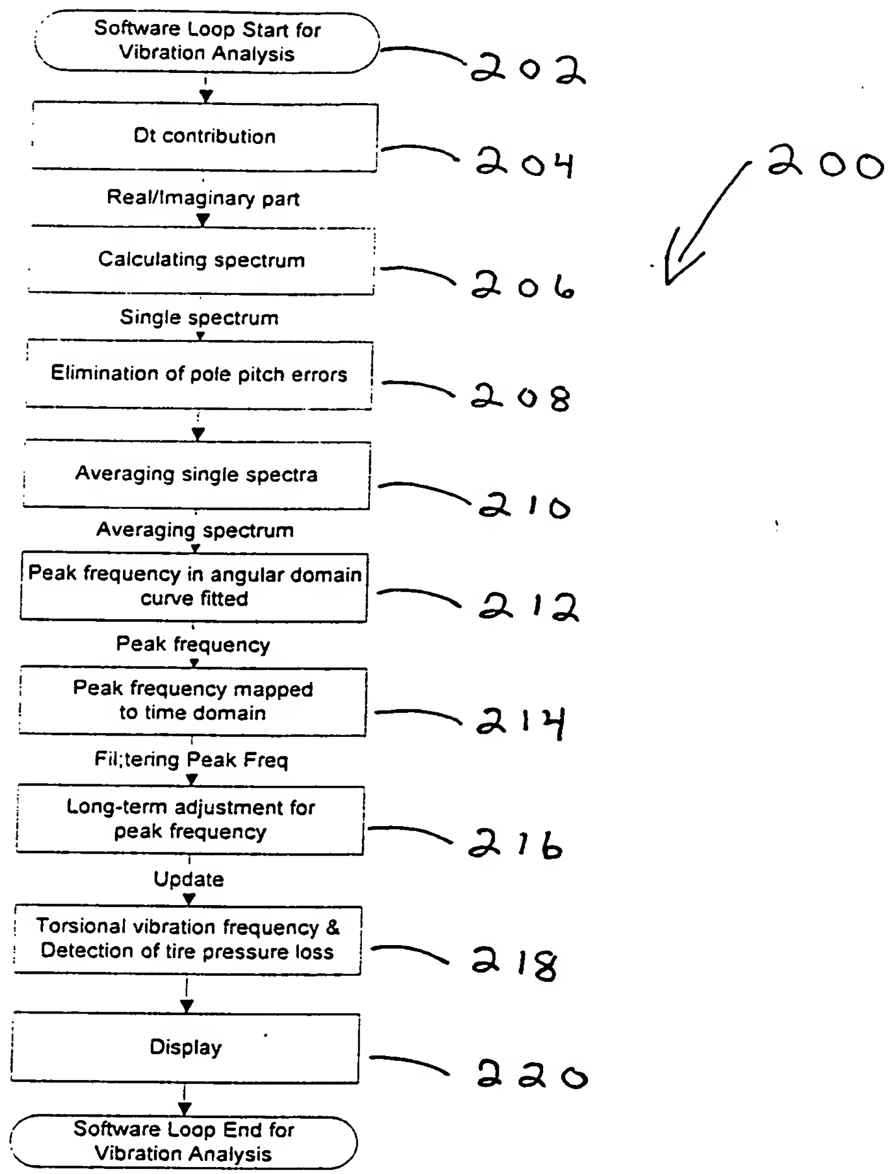
Software Loop Start for Vibration Analysis
202
Dt contribution
204
200
Real/Imaginary part
Calculating spectrum
206
Single spectrum
Elimination of pole pitch errors
208
Averaging single spectra
210
Averaging spectrum
Peak frequency in angular domain curve fitted
212
Peak frequency
Peak frequency mapped to time domain
214
Fil;tering Peak Freq
Long-term adjustment for peak frequency
216
Update
Torsional vibration frequency & Detection of tire pressure loss
218
Display
220
Software Loop End for Vibration Analysis

FIG. 12

SERIAL N~ ________________ CASE NO.___ ____________

FILED:________________ CLIENT CASE NO.__________

APPLI~~ Serial No.: Unknown

Applicant: KOEBE, ET AL.

Client/Matter No.: 10543-074

22553 U.S. PTO

10/769215

013104

THE P.

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EMS:

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Please acknowledge receipt of the below identified:

Items Mailed: **Patent Application Transmittal; 20 Pages of Application; 6 Sheets of Drawings; Unexecuted Combined Declaration and Power of Attorney (3 pages); Information Disclosure Statement; One Sheet of Form PTO-1449 and copies of references cited; and a check in the amount of $770.00 for the filing fee.**

BRINKS HOFER GILSON & LIONE
By: John M. Card. Reg. No. 48,423
Date of Mailing: **January 30, 2004**

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Mailed ______________ Atty JCA ________ Secretary TLW ________

Attorney Docket No.: 10543-074
Client Reference: AB120

DECLARATION AND POWER OF ATTORNEY ORIGINAL APPLICATION

As a below named inventor, I hereby declare:

My residence, post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor or an original, first and joint inventor of the subject matter that is claimed and for which a patent is sought on the invention entitled:

TIRE PRESSURE LOSS DETECTION

the specification of which (check one)

☒ is attached hereto.

☐ was filed on ______________ as United States Application Application No. __________ and was amended on __________ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge my duty to disclose to the United States Patent and Trademark Office all information that I know to be material to the patentability of this application as defined in Title 37 C.F.R. § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s): Priority Not Claimed

(Number)	(Country)	(Filing Date)	☐
(Number)	(Country)	(Filing Date)	☐
(Number)	(Country)	(Filing Date)	☐

I hereby claim the benefit under 35 U.S. C. Section 119(e) of any United States provisional application(s) listed below:

(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)

Attorney Docket No.: 10543-074
Client Reference: AB120

I hereby claim the benefit under 35 U.S.C. Section 120 of any United States applications(s). or Section 365(c) of any PCT International Application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C.F.R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

(Application Serial No.)	(Filing Date)	(Status: patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status: patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status: patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the registered practitioners associated with the customer number printed below as my attorneys, with full power of substitution and revocation, to prosecute this application and transact all business in the United States Patent and Trademark Office connected therewith, and to act on my behalf before the competent International Authorities in connection with any and all international applications filed by me.

00757

Address all correspondence and telephone calls to:

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Andreas Koebe

Sole or first inventor's signature — Date

Residence
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Citizenship
Germany

Post Office Address
Same as above

Attorney Docket No.: 10543-074
Client Reference: AB120

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Second inventor's signature	Date
Residence	56851 Kirkridge TRL, Shelby Twp., MI 48326
Citizenship	US
Post Office Address	Same as above

Full name of third inventor, if any	Peter Olejnik
Third inventor's signature	Date
Residence	Kapersburgstrasse 14, 61191 Rosbach, Germany
Citizenship	Germany
Post Office Address	Same as above

Full name of fourth inventor, if any	Ines Runge
Fourth inventor's signature	Date
Residence	Wunstorfer Str. 33, 30453 Hannover, Germany
Citizenship	Germany
Post Office Address	Same as above

Full name of fifth inventor, if any	
Fifth inventor's signature	Date
Residence	
Citizenship	
Post Office Address	

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Appln. of:	KOEBE, et al
Appln. No.:	10/769,215
Filed:	January 30, 2004
For:	TIRE PRESSURE LOSS DETECTION
Attorney Docket No:	10543-074

Examiner: Unknown
Art Unit: Unknown

Commissioner for Patents
U.S. Patent and Trademark Office
P. O. Box 1450
Alexandria, VA 22313-1450

DECLARATION OF TERRY WAND UNDER 37 C.F.R. §1.10(d)

Dear Sir:

I, Terry Wand, hereby declare that:

1. I am the legal secretary for John M. Card, an attorney with Brinks Hofer Gilson & Lione.

2. At the request of John M. Card, I deposited the above-referenced Patent Application, a Utility Transmittal, 6 sheets of drawings, an Unexecuted Combined Declaration and Power of Attorney, an Information Disclosure Statement, a PTO Form 1449 (one sheet) as "Express Mail" in the Brinks Hofer Gilson & Lione Express Mail outgoing mailbox on January 30, 2004.

3. The Express Mail envelope, Patent Application, and Utility Transmittal all included the Express Mail label number EV329459312US.

4. The copies enclosed herewith are true copies of the correspondence and mailing label as originally mailed.

5. All statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that

these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statement may jeopardize the validity of the above-identified application, and any patent issuing thereon or any patent to which this declaration is direction.

Dated: June 8, 2004   Terry Wand
Terry Wand

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P.O. Box 10395
Chicago, IL 60610